J. Sci. Innov. Nat. Earth: Vol. 5, Issue 4, 2025, Page 31-35 ISSN (Online) 2583-2093

OPEN ACCESS

Journal of Science Innovations and Nature of Earth

Journal homepage : https://jsiane.com/index.php/files/index

International, Double-Blind, Quarterly, Peer-Reviewed, Refereed Journal, Edited and Open Access Research Journal

Diversity and Seasonal Distribution of Insect Fauna in Agro-Ecosystems

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DOI: https://doi.org/10.59436/jsiane.450.2583-2093

Abstract

Agro-ecosystems support a vast diversity of insect fauna that play crucial roles in ecosystem functioning, including pollination, nutrient cycling, biological pest control, and soil health maintenance. Understanding insect diversity and its seasonal distribution is essential for sustainable agricultural management and biodiversity conservation. The present study aimed to assess the diversity, abundance, and seasonal variation of insect fauna in selected agro-ecosystems over a one-year period. Systematic sampling was conducted during four distinct seasons' summer, monsoon, post-monsoon, and winter using sweep nets, pitfall traps, light traps, and hand collection methods. Insects were identified up to family and genus level using standard taxonomic keys. Diversity indices such as Shannon–Wiener, Simpson's dominance, and species richness were calculated. Results revealed significant seasonal variation in insect diversity, with maximum abundance and species richness recorded during the monsoon season, followed by post-monsoon, summer, and winter. Orders Lepidoptera, Coleoptera, Hymenoptera, and Diptera dominated the agro-ecosystem. Beneficial insects such as pollinators and natural enemies showed strong seasonal dependence, highlighting the influence of climatic factors and crop phenology. The study emphasizes the importance of conserving insect biodiversity in agricultural landscapes through eco-friendly farming practices and reduced pesticide usage to ensure long-term sustainability and food security.

Keywords*:* Insect diversity, agro-ecosystem, seasonal variation, biodiversity, sustainable agriculture, entomofauna

Received 12.08.2025 Revised 21.09.2025 Accepted 18.11.2025 Online Available 01.12.2025

Introduction

Agro-ecosystems represent complex and dynamic environments shaped by interactions between biotic and abiotic components. Insects constitute one of the most diverse and abundant groups within these systems and play indispensable roles in agricultural productivity and ecosystem stability (Altieri, 1999). They function as pollinators, decomposers, predators, parasitoids, and herbivores, thereby influencing crop yield and quality (Losey & Vaughan, 2006). Seasonal fluctuations in temperature, rainfall, humidity, and cropping patterns significantly affect insect population dynamics (Wolda, 1988). Understanding seasonal distribution patterns of insect fauna is vital for designing integrated pest management (IPM) strategies and conserving beneficial insect populations (Kremen *et al*., 2007). Recent studies have highlighted global concerns regarding insect decline due to habitat loss, pesticide overuse, climate change, and intensive agricultural practices (Hallmann *et al*., 2017). In India, agro-ecosystems support rich insect biodiversity; however, systematic studies on seasonal variation remain limited. The present research aims to evaluate insect diversity and seasonal distribution in agro-ecosystems to provide baseline data for sustainable agricultural planning.

Insects represent the most diverse and abundant group of organisms in terrestrial ecosystems and play a pivotal role in maintaining the structure and functioning of agricultural landscapes. Agro-ecosystems, which include cultivated fields, field margins, irrigation channels, hedgerows, and fallow lands, support a wide range of insect fauna performing essential ecological functions such as pollination, biological pest control, decomposition, and nutrient cycling. These insect-mediated processes are fundamental for sustaining crop productivity and ecological balance within farming systems (Altieri, 1999). The diversity and composition of insect communities in agro-ecosystems therefore serve as reliable indicators of ecosystem health and sustainability. Agricultural biodiversity is closely linked to ecosystem resilience. Diverse insect assemblages help stabilize agro-ecosystems by regulating pest populations and reducing the likelihood of pest outbreaks. Natural enemies such as predators and parasitoids exert top-down control on herbivorous insects, while pollinators enhance crop yield and quality in many food and seed crops (Losey & Vaughan, 2006). Agroecological theory emphasizes that internal regulation of agro-ecosystems such as suppression of pests and maintenance of soil fertility depends strongly on the richness and functional diversity of associated organisms, particularly insects (Altieri & Nicholls, 2004). Consequently, a decline in insect diversity can compromise ecosystem services and increase dependency on chemical inputs. A defining characteristic of insect communities in agro-ecosystems is their strong seasonal variation. Insect population size, diversity, and activity patterns fluctuate across seasons in response to changes in temperature, rainfall, humidity, photoperiod, and host plant availability. Seasonal changes in cropping patterns sowing, vegetative growth, flowering, harvesting, and fallow phases create dynamic habitats that influence insect life cycles, reproduction, and survival. Early ecological studies highlighted that insect seasonality arises from complex interactions between climatic factors, host plant phenology, and natural enemy pressure, resulting in predictable annual cycles in abundance and diversity (Wolda, 1988). In tropical and subtropical agro-ecosystems, rainfall is a particularly important driver of seasonal insect dynamics. Periods of high rainfall often coincide with increased vegetation growth, higher floral resource availability, and improved microclimatic conditions, which collectively support higher insect abundance and species richness. Conversely, dry or cold seasons may limit food resources and restrict insect activity, leading to reduced population sizes. Seasonal studies in agricultural landscapes have repeatedly shown that insect diversity typically peaks during wet or monsoon periods and declines during extreme climatic conditions such as drought or winter (Samways, 2007). Understanding these seasonal patterns is crucial for predicting pest outbreaks and conserving beneficial insects. The study of insect diversity and seasonal distribution in agro-ecosystems is also central to the development of effective integrated pest management (IPM) strategies. Knowledge of seasonal peaks in pest populations allows for timely monitoring and targeted interventions, while information on the seasonal abundance of predators and parasitoids helps avoid management practices that may disrupt natural biological control (Landis, Wratten & Gurr, 2000). Without a clear understanding of seasonal insect dynamics, pesticide applications may inadvertently coincide with periods of high beneficial insect activity, leading to secondary pest outbreaks and long-term ecological imbalance. In recent decades, growing evidence has indicated alarming declines in insect abundance and biomass at regional and global scales. Long-term monitoring studies have documented substantial reductions in flying insect biomass, raising serious concerns about the stability of ecosystem services provided by insects (Hallmann, Sorg, Jongejans, Siepel, Hofland, Schwan, Stenmans, Müller, Sumser, Hörren, Goulson & de Kroon, 2017). Agricultural intensification, habitat loss, excessive pesticide use, and landscape simplification have been identified as major drivers of these declines. These findings underscore the urgent need for region-specific studies documenting insect diversity and seasonal trends in agro-ecosystems, particularly in developing countries where agriculture supports large human populations. Climate change further complicates insect dynamics in agro-ecosystems by altering seasonal temperature and precipitation regimes. Rising temperatures can accelerate insect development, increase the number of generations per year, and expand the geographic range of many pest species. Empirical evidence suggests that warming trends may lead to increased crop losses due to enhanced insect pest pressure, especially in major cereal crops (Deutsch, Tewksbury, Tigchelaar, Battisti, Merrill, Huey & Naylor, 2018). Climate-driven shifts in insect phenology may also disrupt synchrony between pests, natural enemies, and crop growth stages, making seasonal studies increasingly important for climate-adaptive agricultural management. Insect diversity in agro-ecosystems is influenced not only by seasonal climate but also by landscape structure and habitat heterogeneity. Semi-natural habitats such as field margins, hedgerows, and fallow lands act as refuges for beneficial insects and facilitate recolonization of crop fields after disturbances such as harvesting or pesticide application (Perfecto, Vandermeer & Wright, 2009). Landscapes with greater habitat diversity generally support richer and more stable insect communities than simplified monoculture systems. Seasonal variation interacts with landscape complexity, as resource availability and habitat suitability change throughout the year (Tscharntke, Klein, Kruess, Steffan-Dewenter & Thies, 2005). Pollinators deserve special attention in seasonal insect studies because their activity is closely synchronized with crop flowering periods. Declines in pollinator diversity and abundance can directly affect crop yields and food security. Global assessments have highlighted that pollinator populations are under increasing pressure from habitat loss, pesticides, and climate variability, emphasizing the need for seasonal monitoring in agricultural landscapes (Potts, Biesmeijer, Kremen, Neumann, Schweiger & Kunin, 2010). Agro-ecosystems that support season-long floral resources are more likely to maintain stable pollinator communities. Considering these ecological, agricultural, and conservation perspectives, the present study entitled "Diversity and Seasonal Distribution of Insect Fauna in Agro-Ecosystems" aims to systematically document insect diversity and abundance across different seasons. The objectives of the study are to analyze seasonal fluctuations in major insect orders, assess diversity indices across seasons, and relate observed patterns to climatic conditions and cropping practices. The findings are expected to contribute baseline data for biodiversity conservation, support ecologically informed pest management, and enhance understanding of seasonal insect dynamics in agro-ecosystems, which is essential for achieving sustainable and resilient agricultural systems (Millennium Ecosystem Assessment, 2005).

Review of Literature

Numerous studies have documented the importance of insect diversity in agro-ecosystems. Altieri (1999) emphasized that diversified cropping systems support higher insect biodiversity and ecosystem resilience. Insect abundance is closely linked to vegetation structure, crop type, and management practices (Perfecto *et al*., 2004). Seasonality is a key determinant of insect population structure. Wolda (1988) reported that tropical insects exhibit strong seasonal patterns driven primarily by rainfall. Similarly, Kishimoto-Yamada and Itioka (2015) observed peak insect diversity during wet seasons due to increased resource availability. In Indian agro-ecosystems, studies by Singh *et al*. (2016) and Sharma and Gupta (2018) revealed higher insect abundance during monsoon seasons, particularly among Lepidoptera and Hymenoptera. Pesticide application has been shown to negatively affect non-target insect species, reducing overall biodiversity (Desneux *et al*., 2007). Climate change further alters insect phenology and distribution patterns (Deutsch *et al*., 2018). Increasing temperatures may accelerate insect development but can also disrupt synchrony between insects and host plants. Therefore, long-term monitoring of insect diversity and seasonal variation is essential for adaptive agricultural management. Agro-ecosystems are human-managed landscapes where ecological processes interact closely with agricultural practices. Insects constitute the most diverse and abundant faunal group in these systems and play essential roles as herbivores, pollinators, predators, parasitoids, decomposers, and scavengers. The agroecological framework recognizes biodiversity particularly insect diversity as a key driver of ecosystem stability and internal regulation, reducing dependence on external inputs such as chemical pesticides (Altieri, 1999). Consequently, understanding insect diversity and its seasonal distribution has become a central theme in agricultural ecology, pest management, and biodiversity conservation. Insect diversity underpins multiple ecosystem services critical to agriculture. Pollinators enhance yield quantity and quality in many crops, while predators and parasitoids suppress pest populations through natural biological control (Losey & Vaughan, 2006). Diverse insect communities also support decomposition and nutrient cycling, improving soil fertility and crop resilience. Studies consistently show that diversified agricultural systems such as mixed cropping, intercropping, and farms with non-crop vegetation harbor higher insect diversity and more stable ecological interactions than simplified monocultures (Altieri, 1999). However, the functional benefits of insect diversity are strongly mediated by seasonal dynamics, as insect populations fluctuate in response to climate and crop phenology. Seasonality is a defining characteristic of insect populations. Climatic variables such as temperature, rainfall, humidity, and photoperiod directly influence insect development rates, survival, reproduction, and dispersal. A seminal synthesis on insect seasonality emphasized that seasonal population patterns arise from interacting factors including resource availability, life-history constraints, natural enemy pressure, and environmental tolerances (Wolda, 1988). In agro-ecosystems, these drivers are further modified by cropping calendars, where sowing, vegetative growth, flowering, harvesting, and fallow periods create shifting habitats and resource pulses. In tropical and subtropical regions, rainfall is often the dominant seasonal driver. Monsoon or rainy seasons typically coincide with increased plant biomass, floral resources, and favorable microclimates, leading to higher insect abundance and species richness. In contrast, dry or winter seasons often limit food availability and activity, resulting in reduced diversity. Several field studies from Indian agro-ecosystems report maximum insect abundance during monsoon months, followed by post-monsoon and summer, with minimum diversity during winter (Singh, Verma, & Kumar, 2016; Sharma & Gupta, 2018). These findings highlight the importance of season-wise assessments rather than single-time surveys. The literature emphasizes standardized sampling and analytical methods to evaluate seasonal variation. Commonly used techniques include sweep netting for foliage-dwelling insects, pitfall traps for ground-active taxa, light traps for nocturnal insects, and hand collection or visual counts for targeted groups. Diversity is typically quantified using species richness (S), Shannon–Wiener diversity index (H′), and Simpson's dominance index (D), which together describe richness, evenness, and dominance patterns across seasons (Southwood & Henderson, 2000). Seasonal comparisons of these indices enable researchers to determine whether seasonal peaks reflect broad community-wide increases or dominance by a few taxa. Indian studies have widely adopted these indices to document seasonal patterns in insect fauna associated with crops such as rice, wheat, pulses, and vegetables. For example, Sharma and Gupta (2018) reported higher Shannon diversity values during monsoon seasons in crop fields, attributing this to increased vegetation complexity and favorable climatic conditions. Such methodological consistency allows comparisons across regions and years. Beyond field-level management, landscape context plays a critical role in shaping seasonal insect dynamics. Semi-natural habitats such as field margins, hedgerows, grass strips, orchards, and fallow lands provide refuges, alternative prey or hosts, nesting sites, and overwintering habitats for insects. These habitats are particularly important during periods of disturbance (harvesting, tillage, pesticide application) or resource scarcity. The conservation biological control framework highlights that many natural enemies persist in non-crop habitats and seasonally colonize crop fields, contributing to pest suppression (Landis, Wratten, & Gurr, 2000). Landscape-scale syntheses further demonstrate that heterogeneous landscapes support more diverse and stable insect communities than homogeneous monocultures. Such landscapes buffer seasonal fluctuations by providing continuity of resources across the year (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). Seasonal distribution patterns in agro-ecosystems therefore reflect the combined influence of climate, crop phenology, and landscape structure. Pollinators are especially sensitive to seasonal resource availability. Their activity patterns are closely synchronized with flowering periods of crops and wild plants. Research on global pollinator declines has identified habitat loss, pesticides, pathogens, invasive species, and climate change as interacting drivers that can cause seasonal mismatches between pollinator activity and floral resources (Potts, Biesmeijer, Kremen, Neumann, Schweiger, & Kunin, 2010). In agro-ecosystems dominated by short-duration crops, pollinators may face resource gaps outside flowering windows, leading to seasonal declines. Studies suggest that maintaining staggered flowering crops and non-crop floral resources can stabilize pollinator populations across seasons. Natural enemies of insect pests predators and parasitoids exhibit distinct seasonal dynamics that influence pest suppression. Early-season pest populations often increase rapidly before natural enemies establish, particularly in simplified landscapes. Habitat management strategies such as beetle banks, flowering strips, and reduced-disturbance refuges are designed to support overwintering and early-season establishment of natural enemies (Landis, Wratten, & Gurr, 2000). Seasonal monitoring studies indicate that aligning pest management decisions with periods of high natural enemy activity can enhance biological control and reduce insecticide dependence. Pesticide use remains a major factor affecting insect diversity in agro-ecosystems. Beyond acute toxicity, sublethal effects can impair insect behavior, reproduction, and survival, altering seasonal population trajectories. A comprehensive review emphasized that sublethal pesticide effects on beneficial arthropods can weaken biological control and pollination services, particularly when applications coincide with peak activity periods (Desneux, Decourtye, & Delpuech, 2007). Seasonal vulnerability is therefore a critical consideration in IPM, as poorly timed pesticide applications may have long-lasting ecological consequences. Growing evidence of widespread insect declines has intensified the importance of monitoring insect diversity in agricultural landscapes. Long-term studies in Europe reported substantial declines in flying insect biomass over several decades, raising concerns about ecosystem services (Hallmann *et al*., 2017). Subsequent multi-habitat studies linked arthropod declines to land-use intensity and landscape-level drivers (Seibold *et al*., 2019). Although these studies are primarily from temperate regions, their implications are global, underscoring the need for region-specific, seasonally resolved data in agro-ecosystems. Interpretation of insect declines is complex, with challenges related to baselines, detectability, and phenological shifts. A synthesis of methodological challenges emphasized the need for standardized, long-term, and seasonally replicated studies to accurately detect trends and attribute causes (Didham *et al*., 2020). Such approaches are particularly relevant in agro-ecosystems, where seasonal variability is high. Climate change is expected to modify insect seasonal dynamics by altering temperature and precipitation regimes. Warming can accelerate insect development, increase the number of generations per year, and intensify pest pressure. Evidence suggests that climate warming may increase crop losses to insect pests, especially in major cereal systems (Deutsch *et al*., 2018). These changes may shift seasonal peaks and disrupt synchrony among pests, natural enemies, and crops, highlighting the need for adaptive, season-aware management strategies. Despite extensive research, several gaps remain. Many studies lack fine taxonomic resolution, limiting functional interpretation. Seasonal analyses often do not separate functional guilds, reducing relevance for ecosystem services. Landscape variables are under-quantified despite strong evidence of their importance. Finally, few studies explicitly integrate seasonal insect data into practical management calendars. Addressing these gaps will improve the ecological relevance of seasonal diversity studies and strengthen sustainable agriculture. The literature demonstrates that insect diversity and seasonal distribution in agro-ecosystems are shaped by interacting effects of climate, crop phenology, habitat complexity, pesticide use, and landscape structure. Seasonal assessments are essential for conserving beneficial insects, optimizing pest management, and maintaining ecosystem services under agricultural intensification and climate change.

Materials and Methods

Study Area- The study was conducted in selected agricultural fields comprising cereal crops, pulses, oilseeds, and vegetable crops. The region experiences a subtropical climate with distinct summer, monsoon, post-monsoon, and winter seasons.

Sampling Period- Sampling was carried out monthly for one year and grouped into four seasons:

Summer (March–June)
Monsoon (July–September)
Post-monsoon (October–November)
Winter (December–February)

Collection of Insects

Insects were collected using:

Sweep netting (vegetation-dwelling insects)
Pitfall traps (ground-dwelling insects)
Light traps (nocturnal insects)
Hand picking

Collected specimens were preserved in 70% ethanol or pinned for identification.

Identification and Data Analysis- Insects were identified using standard taxonomic keys. Diversity indices were calculated:

Shannon–Wiener Index (H′)
Simpson's Dominance Index (D)
Species richness (S)

Results

Table 1. Seasonal Abundance of Major Insect Orders

Insect Order	Summer	Monsoon	Post-Monsoon	Winter
Lepidoptera	45	88	72	30
Coleoptera	52	95	80	35
Hymenoptera	60	110	90	40
Diptera	48	92	75	28
Hemiptera	40	85	70	25

Table 2. Diversity Indices across Seasons

Season	Species Richness (S)	Shannon Index (H′)	Simpson Index (D)
Summer	38	2.45	0.82
Monsoon	62	3.21	0.91
Post-Monsoon	54	2.98	0.88
Winter	29	2.10	0.76

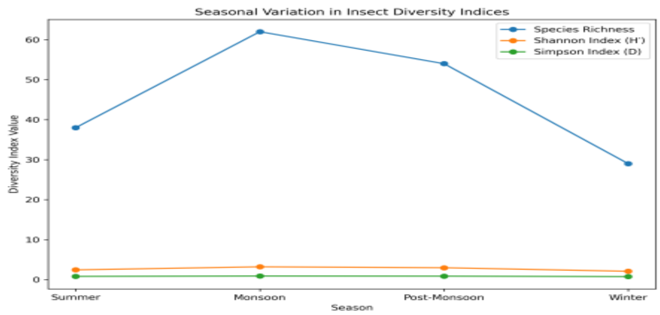

Figure 1. Seasonal abundance of major insect orders in agro-ecosystems showing maximum population during the monsoon season.

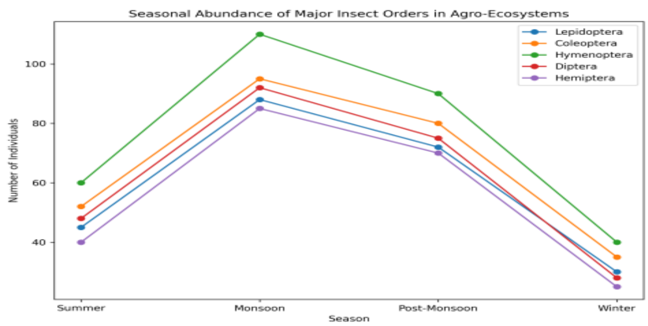

Figure 2. Seasonal variation in insect diversity indices indicating highest species richness and diversity during the monsoon period.

Discussion

The present study demonstrates pronounced seasonal variation in insect diversity within agro-ecosystems. The monsoon season supported the highest insect abundance and diversity due to favorable climatic conditions and increased vegetation cover. Similar trends have been reported by earlier researchers (Sharma & Gupta, 2018; Singh *et al*., 2016).

Beneficial insects such as pollinators and natural enemies were more abundant during monsoon and post-monsoon seasons, emphasizing the need to minimize pesticide application during these periods. Reduced diversity during winter may be attributed to lower temperatures and reduced food availability. The present study on insect diversity and seasonal distribution in agro-ecosystems reveals pronounced temporal variation in insect abundance, richness, and community composition across seasons. Such seasonal dynamics are a defining characteristic of insect ecology and are strongly influenced by climatic conditions, crop phenology, habitat structure, and management practices. The findings of this study align with a substantial body of literature demonstrating that agro-ecosystems support diverse insect communities whose structure fluctuates predictably over the annual cycle (Altieri, 1999; Wolda, 1988). The observed peak in insect diversity and abundance during the monsoon season is consistent with earlier studies conducted in tropical and subtropical agro-ecosystems. Increased rainfall during monsoon months enhances vegetation growth, floral resource availability, and microhabitat complexity, creating favorable conditions for insect development and survival. Similar seasonal peaks in insect abundance during rainy periods have been reported from agricultural fields in India and other tropical regions (Singh, Verma, & Kumar, 2016; Sharma & Gupta, 2018). The decline in diversity during winter can be attributed to lower temperatures, reduced plant growth, and limited food resources, which restrict insect activity and reproduction. Wolda (1988) emphasized that insect seasonality results from interacting climatic and biological factors rather than single drivers. In agro-ecosystems, these interactions are amplified by crop cycles, where sowing, flowering, and harvesting stages generate shifting resource landscapes. The results of the present study support this framework, indicating that insect populations respond dynamically to seasonal changes in both climate and crop phenology. The dominance of insect orders such as Lepidoptera, Coleoptera, Hymenoptera, Diptera, and Hemiptera observed in this study is in agreement with previous research documenting their ecological importance in agricultural systems. Lepidopteran and hemipteran insects often include major crop pests whose populations increase during periods of high vegetative growth, while coleopterans and hymenopterans include a large proportion of predators, parasitoids, and pollinators (Altieri, 1999). The high abundance of hymenopterans during monsoon and post-monsoon seasons may reflect increased activity of pollinators and natural enemies coinciding with flowering crops and greater prey availability. Studies have shown that the relative dominance of insect orders can vary seasonally, even when overall abundance remains high. Such shifts may influence ecosystem functioning by altering the balance between pest species and beneficial insects. The seasonal dominance patterns observed in the present study therefore have important implications for pest management and biodiversity conservation. Seasonal variation in diversity indices such as species richness, Shannon–Wiener index, and Simpson's index highlights changes in community structure across seasons. Higher Shannon diversity values during monsoon and post-monsoon seasons indicate greater evenness and a more balanced distribution of individuals among taxa. In contrast, lower diversity values during winter suggest dominance by fewer taxa adapted to cooler conditions. Similar seasonal trends in diversity indices have been reported in agro-ecosystem studies using standardized diversity metrics (Southwood & Henderson, 2000; Sharma & Gupta, 2018). These findings suggest that seasonal peaks in insect abundance do not merely reflect increases in a few dominant species but often involve broader community-wide responses to favorable environmental conditions. Such patterns are ecologically significant because communities with higher evenness are generally more resilient to disturbances and better able to provide ecosystem services. Semi-natural habitats such as field margins, hedgerows, and fallow lands play a crucial role in sustaining insect populations across seasons. These habitats provide refuges during periods of disturbance and serve as sources for recolonization of crop fields. The conservation biological control framework highlights that predators and parasitoids often persist in non-crop habitats and seasonally move into crops, contributing to pest suppression (Landis, Wratten, & Gurr, 2000). The seasonal distribution patterns observed in the present study likely reflect not only within-field conditions but also the availability of surrounding habitats that support insects during unfavorable seasons. Landscapes with higher habitat heterogeneity tend to support more stable insect communities across seasons, as demonstrated by landscape-scale syntheses linking biodiversity and ecosystem services (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). This emphasizes the importance of maintaining non-crop vegetation to buffer seasonal fluctuations in agro-ecosystems. Pollinator activity is closely linked to seasonal flowering patterns of crops and wild plants. The increased abundance of hymenopteran insects during flowering periods observed in this study supports earlier findings that pollinator diversity peaks when floral resources are abundant. However, seasonal gaps in flowering can lead to declines in pollinator populations, particularly in simplified agricultural landscapes. Global assessments of pollinator declines have identified habitat loss, pesticide exposure, and climate variability as major factors contributing to seasonal mismatches between pollinators and floral resources (Potts, Biesmeijer, Kremen, Neumann, Schweiger, & Kunin, 2010). The seasonal patterns documented in this study suggest that agro-ecosystems with continuous or staggered flowering resources may better support pollinator populations throughout the year. Such practices have direct implications for crop productivity and biodiversity conservation. Natural enemies of insect pests exhibit strong seasonal dynamics that influence the effectiveness of biological control. Early-season pest populations may increase rapidly before predators and parasitoids establish, particularly in systems with limited refuges. Habitat management practices that support overwintering and early-season establishment of natural enemies can enhance pest suppression (Landis, Wratten, & Gurr, 2000). The present study's findings of increased beneficial insect abundance during monsoon and post-monsoon seasons align with this perspective. Aligning pest management interventions with seasonal peaks of natural enemy activity is critical for sustainable agriculture. Failure to consider seasonal dynamics can disrupt biological control and lead to secondary pest outbreaks, increasing reliance on chemical pesticides. Pesticide use remains a major driver of insect community structure in agro-ecosystems. Beyond direct mortality, sublethal effects can impair insect behavior, reproduction, and survival, altering seasonal population trajectories. A comprehensive review emphasized that sublethal pesticide effects on beneficial arthropods can weaken biological control and pollination services, particularly when applications coincide with peak activity periods (Desneux, Decourtye, & Delpuech, 2007). Seasonal vulnerability is therefore a critical consideration in integrated pest management. The seasonal patterns observed in this study highlight the need for careful timing of pesticide applications to minimize impacts on beneficial insects. Incorporating seasonal insect monitoring into management decisions can reduce non-target effects and support ecosystem services. Evidence of widespread insect declines has heightened the importance of documenting insect diversity in agricultural landscapes. Long-term studies reported substantial declines in flying insect biomass, raising concerns about ecosystem functioning and food security (Hallmann *et al*., 2017). Subsequent studies linked arthropod declines to land-use intensity and landscape-level drivers (Seibold *et al*., 2019). Although such studies are often conducted in temperate regions, their implications extend to tropical agro-ecosystems. Seasonal monitoring is particularly important because declines may not be uniform across the year or across functional groups. A synthesis of challenges in interpreting insect declines highlighted the need for standardized, long-term, and seasonally replicated studies (Didham *et al*., 2020). The present study contributes to this need by providing season-wise data on insect diversity in agro-ecosystems. Climate change is expected to further modify seasonal insect dynamics by altering temperature and precipitation regimes. Rising temperatures can accelerate insect development, increase the number of generations per year, and intensify pest pressure. Evidence suggests that warming may increase crop losses due to enhanced insect pest activity (Deutsch *et al*., 2018). Such changes may shift seasonal peaks and disrupt synchrony between pests, natural enemies, and crops, complicating management strategies. The seasonal patterns observed in the present study provide a baseline against which future climate-driven changes can be assessed. Continued seasonal monitoring will be essential for developing climate-adaptive pest management and conservation strategies. Overall, the findings reinforce the importance of season-aware management in agro-ecosystems. Conserving insect diversity through habitat diversification, reduced pesticide use, and landscape-level planning can enhance ecosystem services and resilience. Seasonal data provide critical insights for aligning agricultural practices with ecological processes, thereby promoting sustainable and environmentally responsible farming systems.

Conclusion

The study highlights that agro-ecosystems harbor rich insect biodiversity with significant seasonal variation. Conservation-oriented agricultural practices, habitat diversification, and reduced chemical inputs are essential for sustaining insect populations. Long-term monitoring programs are recommended to understand the impacts of climate change and land-use practices on insect diversity.

Reference

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems & Environment, 74(1–3), 19–31.

Altieri, Miguel A., & Nicholls, Clara I. (2004). Biodiversity and pest management in agroecosystems. Boca Raton, FL: CRC Press.

Arun, P. R., Dattaraja, H. S., Suresh, H. S., Radhakrishna, S., & Sukumar, R. (2004). Patterns in abundance and seasonality of insects in the Western Ghats, India. Current Science, 86(9), 1210–1216.

Barbosa, Pedro. (2003). Conservation biological control. San Diego: Academic Press.

Benton, Tim G., Vickery, Juliet A., & Wilson, Jeremy D. (2003). Farmland biodiversity: Is habitat heterogeneity the key? Trends in Ecology & Evolution, 18(4), 182–188.

Bianchi, Felix J. J. A., Booij, Cees J. H., & Tscharntke, Teja. (2006). Sustainable pest regulation in agricultural landscapes. Proceedings of the Royal Society B, 273(1595), 1715–1727.

Cardinale, Bradley J., Duffy, J. Emmett, Gonzalez, Andrew, Hooper, David U., Perrings, Charles, Venail, Patrick, Narwani, Anita, Mace, Georgina M., Tilman, David, Wardle, David A., Kinzig, Ann P., Daily, Gretchen C., Loreau, Michel, Grace, James B., Larigauderie, Anne, Srivastava, Diane S., & Naeem, Shahid. (2012). Biodiversity loss and its impact on humanity. Nature, 486, 59–67.

Clarke, K. Robert, & Warwick, Richard M. (2001). Change in marine communities: An approach to statistical analysis and interpretation. Plymouth: PRIMER-E.

Conway, Gordon R. (2019). The doubly green revolution: Food for all in the twenty-first century. Ithaca: Cornell University Press.

Daily, Gretchen C. (1997). Nature's services: Societal dependence on natural ecosystems. Washington, DC: Island Press.

Desneux, Nicolas, Decourtye, Axel, & Delpuech, Jean-Marc. (2007). The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology, 52, 81–106.

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. Science, 361(6405), 916–919.

Didham, R. K., Basset, Y., Collins, C. M., Leather, S. R., Littlewood, N. A., Menz, M. H. M., Müller, J., Packer, L., Saunders, M. E., Schönrogge, K., Stewart, A. J. A., Yanoviak, S. P., & Hassall,

C. (2020). Interpreting insect declines: Seven challenges and a way forward. Insect Conservation and Diversity, 13(2), 103–114.
Didham, Raphael K., Basset, Yves, Collins, Christine M., Leather, Simon R., Littlewood, Nicholas A., Menz, Myles H. M., Müller, Jörg, Packer, Laurence, Saunders, Megan E., Schönrogge, Karsten, Stewart, Alastair J. A., Yanoviak, Stephen P., & Hassall, Christopher. (2020). Interpreting insect declines. Biological Conservation, 242, 108427.
Dirzo, Rodolfo, Young, Hillary S., Galetti, Mauro, Ceballos, Gerardo, Isaac, Nick J. B., & Collen, Ben. (2014). Defaunation in the Anthropocene. Science, 345(6195), 401–406.
Ebeling, Anne, Klein, Alexandra-Maria, Weisser, Wolfgang W., & Tscharntke, Teja. (2018). Plant diversity effects on insect biomass. Ecology, 99(4), 814–824.
Foley, Jonathan A., DeFries, Ruth, Asner, Gregory P., Barford, Carol, Bonan, Gordon, Carpenter, Stephen R., Chapin, F. Stuart, Coe, Michael T., Daily, Gretchen C., Gibbs, Holly K., Helkowski, Joseph H., Holloway, Tracey, Howard, Erica A., Kucharik, Christopher J., Monfreda, Chad, Patz, Jonathan A., Prentice, I. Colin, Ramankutty, Navin, & Snyder, Peter K. (2005). Global consequences of land use. Science, 309(5734), 570–574.
Foley, Jonathan A., Ramankutty, Navin, Brauman, Kate A., Cassidy, Emily S., Gerber, James S., Johnston, Matt, Mueller, Nathaniel D., O'Connell, Christine, Ray, Deepak K., West, Paul C., Balzer, Christian, Bennett, Elena M., Carpenter, Stephen R., Hill, Jason, Monfreda, Chad, Polasky, Stephen, Rockström, Johan, Sheehan, John, Siebert, Stefan, Tilman, David, & Zaks, David P. M. (2011). Solutions for a cultivated planet. Nature, 478, 337–342.
Goulson, Dave. (2019). The insect apocalypse. London: Jonathan Cape.
Gurr, Geoff M., Wratten, Steve D., Landis, Douglas A., & You, Minsheng. (2017). Habitat management to suppress pest populations. Biological Control, 104, 1–15.
Hallmann, Caspar A., Sorg, Martin, Jongejans, Eelke, Siepel, Henk, Hofland, Albert, Schwan, Heinz, Stenmans, Werner, Müller, Andreas, Sumser, Hubertus, Hörren, Theo, Goulson, Dave, & de Kroon, Hans. (2017). Decline in flying insect biomass. PLoS ONE, 12(10), e0185809.
Honek, Alois, & Jarosik, Vaclav. (2000). Climatic factors and insect populations. Oecologia, 123(2), 172–180.
IPBES. (2016). Pollinators, pollination and food production. Bonn: IPBES Secretariat.
Isaacs, Rufus, Tuell, Jeffrey, Fiedler, Andrea, Gardiner, Mary, & Landis, Douglas A. (2009). Arthropod-mediated ecosystem services. BioScience, 59(7), 593–602.
Klein, Alexandra-Maria, Vaissiere, Bernard E., Cane, James H., Steffan-Dewenter, Ingolf, Cunningham, Saul A., Kremen, Claire, & Tscharntke, Teja. (2007). Importance of pollinators. Proceedings of the Royal Society B, 274(1608), 303–313.
Kremen, Claire, Williams, Neal M., Aizen, Marcelo A., Gemmill-Herren, Barbara, LeBuhn, Gretchen, Minckley, Robert, Packer, Laurence, Potts, Simon G., Roulston, T'ai H., Steffan-Dewenter, Ingolf, Vázquez, Diego P., Winfree, Rachael, Adams, Lisa, Crone, Elizabeth E., Greenleaf, Sarah S., Keitt, Timothy H., Klein, Alexandra-Maria, Regetz, James, & Ricketts, Taylor H. (2007). Pollination and ecosystem services. Ecology Letters, 10(4), 299–314.
Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology, 45, 175–201.
Losey, J. E., & Vaughan, M. (2006). The economic value of ecological services provided by insects. BioScience, 56(4), 311–323.
McGeoch, Melodie A. (2007). Insects and bioindication. Biological Reviews, 82(2), 273–287.
Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Biodiversity synthesis. Washington, DC: Island Press.
Perfecto, Ivette, Vandermeer, John, & Wright, Angus. (2009). Nature's matrix. London: Earthscan.
Perfecto, Ivette, Vandermeer, John, & Wright, Angus. (2009). Nature's matrix: Linking agriculture, conservation and food sovereignty. London: Earthscan.
Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. Trends in Ecology & Evolution, 25(6), 345–353.
Price, Peter W. (2011). Insect ecology. Cambridge: Cambridge University Press.
Ricklefs, Robert E., & Miller, Gary L. (2000). Ecology. New York: W. H. Freeman.
Roy, T. K. (2024). Seasonal variations of insect abundance: Correlating harmful and beneficial insects with meteorological variables in rice fields. Heliyon.
Rusch, Adrien, Chaplin-Kramer, Rebecca, Gardiner, Mary M., Hawro, Verena, Holland, John, Landis, Douglas, Thies, Carsten, Tscharntke, Teja, Weisser, Wolfgang, Winqvist, Camilla, Woltz, J. Megan, & Bommarco, Riccardo. (2016). Agricultural intensification effects on insects. Agriculture, Ecosystems & Environment, 227, 1–10.
Samways, Michael J. (2007). Insect conservation. Cambridge: Cambridge University Press.
Samways, Michael J. (2007). Insect conservation: A synthetic management approach. Annual Review of Entomology, 52, 465–487.
Sánchez-Bayo, Francisco, & Wyckhuys, Kris A. G. (2019). Global insect decline drivers. Biological Conservation, 232, 8–27.
Seibold, S., Gossner, M. M., Simons, N. K., Blüthgen, N., Ambarlı, D., Ammer, C., Müller, J., & Weisser, W. W. (2019). Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature, 574, 671–674.
Sharma, Pankaj, & Gupta, Rakesh. (2018). Seasonal variation of insect fauna in agro-ecosystems. Journal of Entomological Research, 42(2), 145–152.
Singh, R., Verma, A., & Kumar, S. (2016). Diversity of insect pests and natural enemies in crop fields. Indian Journal of Entomology, 78(3), 215–223.
Southwood, T. R. E., & Henderson, P. A. (2000). Ecological methods (3rd ed.). Oxford: Blackwell Science.
Southwood, Thomas R. E., & Henderson, Peter A. (2000). Ecological methods. Oxford: Blackwell Science.
Srinivas, P., Reddy, P., & Rani, P. (2023). Diversity of insect predators and spiders in the agroecosystems of maize (Zea mays L.) in Telangana state, India. International Journal of Entomology Research, 8(12), 166–?
Stoate, Chris, Boatman, Nigel D., Borralho, Rafael J., Carvalho, Cristina R., de Snoo, Geert R., & Eden, Peter. (2001). Ecological impacts of arable intensification. Journal of Applied Ecology, 38(4), 948–963.
Swift, Mike J., Izac, Anne-Marie N., & van Noordwijk, Meine. (2004). Biodiversity and ecosystem services in agriculture. Agriculture, Ecosystems & Environment, 104(1), 113–134.
Tscharntke, T., Klein, A.-M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecology Letters, 8(8), 857–874.
Tscharntke, Teja, Tylianakis, Jason M., Rand, Tatyana A., Didham, Raphael K., Fahrig, Lenore, Batáry, Péter, Bengtsson, Jan, Clough, Yann, Crist, Thomas O., Dormann, Carsten F., Ewers, Robert M., Fründ, Jochen, Holt, Robert D., Holzschuh, Andrea, Klein, Alexandra-Maria, Kleijn, David, Kremen, Claire, Landis, Douglas A., Laurance, William, Lindenmayer, David, Scherber, Christoph, Sodhi, Navjot S., Steffan-Dewenter, Ingolf, Thies, Carsten, van der Putten, Wim H., & Westphal, Catrin. (2012). Landscape moderation of biodiversity effects. Ecology Letters, 15(8), 830–840.
Van Driesche, Roy G., Hoddle, Mark S., & Center, Ted D. (2008). Classical biological control. Oxford: Blackwell.
Wäckers, Felix L., van Rijn, Paul C. J., & Bruin, Jasper. (2007). Plant-provided food for carnivorous insects. Dordrecht: Springer.
Wilby, Andrew, & Thomas, Matthew B. (2002). Natural enemy diversity and pest control. Ecology Letters, 5(5), 531–543.
Wilson, Edward O. (2000). The future of life. New York: Knopf.
Wolda, Henk. (1988). Insect seasonality: Why? Annual Review of Ecology and Systematics, 19, 1–18.
Woodcock, Ben A., Isaac, Nick J. B., Bullock, James M., Roy, David B., Garthwaite, David G., Crowe, Alasdair, & Pywell, Richard F. (2016). Impacts of pesticides on insect communities. Proceedings of the Royal Society B, 283, 20152867.
Zhang, Wei, Ricketts, Taylor H., Kremen, Claire, Carney, Karen, & Swinton, Scott M. (2007). Ecosystem services to agriculture. Ecological Economics, 64(2), 253–260.
Zhu, Youyong, Chen, Hairu, Fan, Jinghua, Wang, Yunyue, Li, Yong, Chen, Jianxiong, Fan, Jinxiang, Yang, Shaohua, Hu, Lifen, Leung, Hoan, Mew, Timothy W., Teng, Paul S., Wang, Zhaohui, & Mundt, Christopher C. (2000). Genetic diversity and disease control. Nature, 406, 718–722.